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TRENCHING MACHINERY USED FOR THE CONSTRUCTION OF TRENCHES FOR TILE DRAINS.

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CONTENTS.

INTRODUCTION.

The invention of suitable appliances for tile trenching has been stimulated by three agencies—the rising prices of labor, the rapid extension of tile drainage for farm lands, and the growing practice of using large tile instead of open ditches of moderate size for community outlets, especially where the depth of cut is rather great. Where wide trenches are dug by hand deeper than 6 or 7 feet, the material must be handled at least twice, since the dirt can not be thrown back from the edge of the trench at the first handling. Besides reducing the amount and cost of labor, a good machine greatly lessens the time necessary for doing the work, which is often of considerable advantage, apart from any saving in direct money cost. Difficulties such

NOTE.—This bulletin describes the types of trenching machines, and discusses the limiting conditions of work and the cost of trenching. It is based upon extended investigations by the writer, supplemented by data secured from manufacturers and contractors and from other drainage engineers. It will be of service to those whose lands need tile drainage. It does not deal with drainage of irrigated lands, where the requirements for good trenching machines are often unusual and the cost of work much greater.

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as occasionally arise where many unskilled workmen are employed may be largely avoided by the use of machinery requiring only a small crew. The many types of equipment for trenching vary from special plows and scoops of ordinary size to elaborate machines costing thousands of dollars. The smaller kinds are limited in depth and width of trench, also in regard to conditions of working. Some variations from the machines described have been manufactured and not found practical; new designs that may be available in the future perhaps will be as good or better than those now on the market.

REQUISITES OF A GOOD MACHINE.

Three things are required of a good trenching machine, namely, (1) it must operate efficiently through various kinds of soil; (2) it must be capable of cutting true to grade; (3) it must work for long periods without breaking or otherwise getting out of order. The first of these requirements is the hardest to fulfill, the second is the easiest.

There are many kinds of soil to be encountered—hard shale, cemented gravel, sand, stones, loose loam, soft muck, and sticky clay. None of the machines will handle solid rock. The ideal machine will handle all kinds of soil, with but minor changes of parts, without breaking or stopping and at a minimum expense for purchase, operation, repairs, and depreciation. Open or skeleton excavating buckets are best suited to sticky soils, while solid buckets are necessary in loose dry soils, though some machines have efficient cleaning devices that permit the use of solid buckets for any kind of material. A machine must be strong to work through shale or stony ground, but if increased strength entails added weight, the efficiency and adaptability may be affected. A heavy machine can not work over soft ground unless fitted with rather costly apron tractors instead of the driving wheels. (See fig. 7.)

GENERAL CLASSES OF TRENCHING MACHINES.

The many types of trenching machines may be divided in four general classes: (1) Plows and scoops, (2) wheel excavators, (3) endless-chain excavators, (4) scraper excavators. The general nature of the plows and scoops is indicated by these names; they are usually operated by horses, and some merely loosen the dirt to make hand shoveling easier. In the wheel excavators the excavating buckets are arranged upon the rim of a wheel. (See fig. 6.) In the endless-chain excavators the excavating buckets are carried on parallel endless chains supported by a long steel frame at the rear of the machine. One end of the frame is lowered so that the buckets are drawn up the end of the trench, cutting a thin slice of earth from the bottom to the top. (See fig. 10.) The scraper machines are the same as the dipper

and drag-line machines designed for wide ditches, sometimes with slight changes in the rigging to give better control of the bucket. The largest machines of the third and fourth classes are adapted to deeper and wider trenching than are those of the other classes.

In the following descriptions of the various types, the letters used to designate the machines have been assigned arbitrarily by the writer for convenient reference.

PLOWS AND SCOOPS.

This class of excavators has been made to include the smaller and less expensive implements, which will be found economical for smaller jobs than would warrant the purchase of the more costly machines. Almost all the plows and scoops are lacking in any device for cutting accurately to grade. Some handwork is necessary to make the trench smooth for laying the tile properly. Many are limited in depth of digging to $2\frac{1}{2}$ or 3 feet, which is not as deep as tile should be laid in many places. Many of these implements are merely aids to hand work, using animal power only to loosen the dirt. The main advantage over the more elaborate trenching machines is their low cost. (See Farmers' Bulletin, No. 524, for information on digging trenches for small fields entailing hand work.)

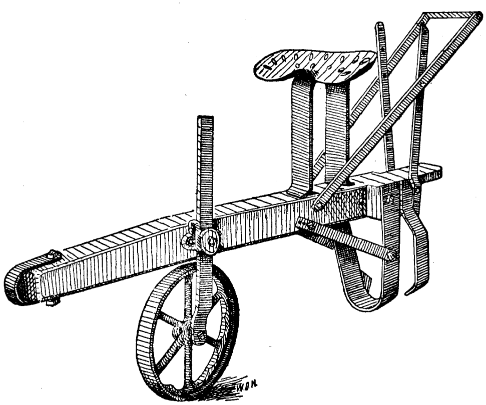

FIG. 1.—Ditching plow A.

DITCHING PLOW A.

Perhaps one of the simplest trenching devices is the ditching plow shown in figure 1, which is used only to loosen the dirt in order that shoveling may be easier. The U-shaped knife does most of the cutting; the side knives just behind keep the sides of the trench vertical. Each plowing cuts about 3 to 6 inches deep. The usual width of the trench is about 12 inches, but the side knives may be spread to cut 16 inches wide. This plow weighs about 165 pounds and costs about $20. Two horses and two men are used with it.

DITCHING PLOW B.

Figure 2 shows another ditching plow for merely loosening the soil. The first furrow along the trench is made with an ordinary plow, then the ditching implement is used. This plow has no moldboard,

and the share cuts 6 inches wide on the bottom. An adjustable slider in front of the plowpoint regulates the depth of each cutting. The plow beam is adjustable vertically, being pivoted on the front arm of the standard and held in the desired position by a segment at the rear end of the beam. The first round of this plow cuts the sides of the trench straight down. The loose earth is then shoveled out, the plow beam is raised, and another round is made; this process is repeated until the desired depth is reached. The minimum width of trench is 8 inches, and the plow works in this width to 3 feet depth without difficulty. Wider trenches can be cut deeper, though it may be necessary to lengthen the distance between the plow and the team. An attachment is made for cutting a smooth groove in the bottom of the trench, in which to lay the tile, but there is no way of cutting to grade with this implement. The plow weighs about 150 pounds and costs about $18. One man is required to drive the horses and one to handle the plow.

Ditching Scoop C.

This implement (fig. 3) consists of a knife or plow working similarly to plow A, and a bucket by which the loosened earth is removed from the trench. The heavy U-shaped steel cutter is mounted on a steel frame, and to the ends of it are bolted trimmers for widening the trench sufficiently to permit easy operation of the scoop. The bucket is $3\frac{1}{2}$ feet long, 17 inches high, and 10 inches in top width. It is hinged to the cutter frame by steel straps. The lower end of the wooden handle is fastened to a loop near the bottom of the bucket. A hook on it engages the top of the bucket between guides that keep the bucket from tipping when the handle is upright.

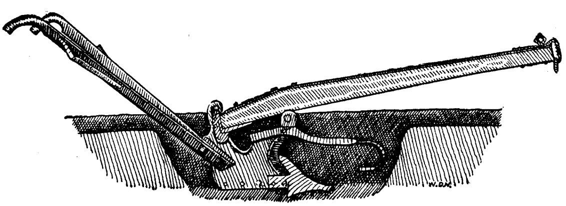

FIG. 2.—Ditching plow B.

Two men and a team are required to operate this scoop, which is filled by being drawn up the sloping end of the completed part of the trench. The depth of each cutting is controlled by an adjustable shoe just in front of the cutting knife. The scoop will hold about 5 cubic feet of dirt, and is usually filled after moving about 8 feet. When full, the scoop slides out of the trench, the handle is lifted to disengage the hook, and the bucket falls on its side. A loop on the bottom of the bucket offers a hold for turning the bucket bottom up, and also takes much of the wear from friction. Perforations in the bottom prevent suction from holding the dirt in the bucket. The team is backed while the scoop is drawn back to position for another cutting.

DITCHING PLOW D.

This is one of the more elaborate plows (fig. 4). The dirt is not only loosened by the plow, but it is also forced up and well to the side of the trench by the wings provided for that purpose. The full depth of the trench is not made at one cutting, but about 5 to 6 inches is removed at each passage of the plow. The trench is 10 inches wide, and the maximum depth is 2½ feet. Attachments may be purchased to make the trench 15 inches wide and 3 feet deep. Six horses and three men (two driving the teams) are ordinarily used. The machine weighs about a ton and costs $250. The side knives to cut the wider trench cost $25 extra, and the device for deeper cutting costs $25 more. The bottom of the trench must be graded by hand unless the ground surface is parallel to the grade for the tile, and even then some trimming or smoothing with the tile scoop should be done.

DITCHING PLOW E.

At first glance this machine (fig. 5) looks something like a wheel excavator, but it is merely a plow with a wheel and belt for lifting the dirt out of the trench. The plow is located under the rear of the elevating wheel, which bears the entire weight of the machine when working. The frame of the machine is lowered until the plow cuts a slice of earth 2 to 6 inches thick, according to the kind and condition of soil; the driver controls the thickness of this slice by levers that change the distance of the plowpoint from the rim of the elevating wheel. This wheel has a wide rim, with flanges about 3 inches deep between which the 8-inch link belt fits easily. The elevating wheel is revolved by friction on the ground, and drives the link belt through a chain connection. As the dirt is loosened by the plow it is caught between the wheel and belt and is carried to the top of the machine, where it is forced off the wheel upon a dirt board that drops it beside the trench. The flanges of the large wheel act as rilling cutters in trimming the sides of the trench. The belt is kept taut by a small movable pulley and a steel spring under the rear driving seat. When one slice has been taken from the bottom of the trench, the frame of the machine, with the plow, wheel, and belt, is

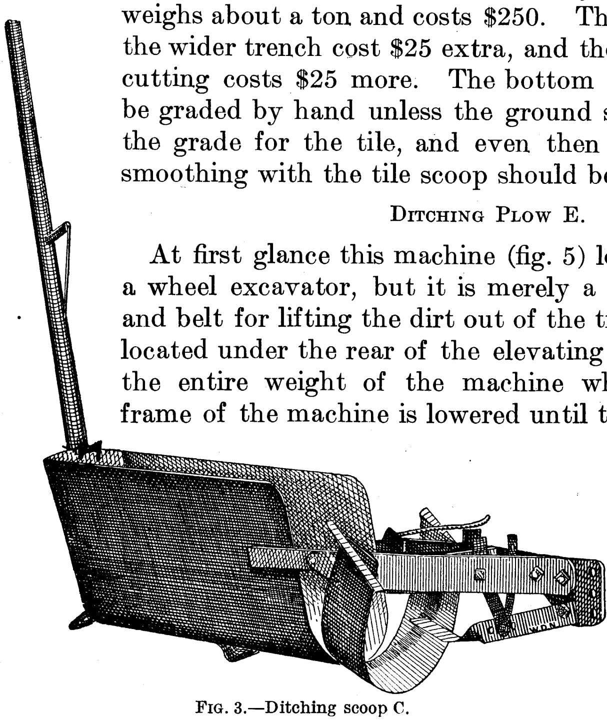

FIG. 3.—Ditching scoop C.

further lowered and another slice is cut. This process is continued until the trench is as deep as is desired, or until the maximum depth for the machine has been reached, which is 36 to 40 inches.

In the manner described, this excavator will dig about 10 inches wide, sufficient for laying 6-inch tile. The illustration shows two trimming knives just back of the plow for making wider trenches. These are made in different sizes, for trenches up to 16 inches wide. As the trimming knives are behind the plow the dirt which they loosen is not removed until the machine makes the next cut through the trench. The dirt board may be raised or lowered to regulate, in a measure, the distance at which the excavated material is placed from the trench. Usually only one man and four horses are needed for operating this plow, although sometimes an extra man is needed for driving until the horses become accustomed to the work. The operator sits in the rear seat. The excavator weighs about a ton and costs $300.

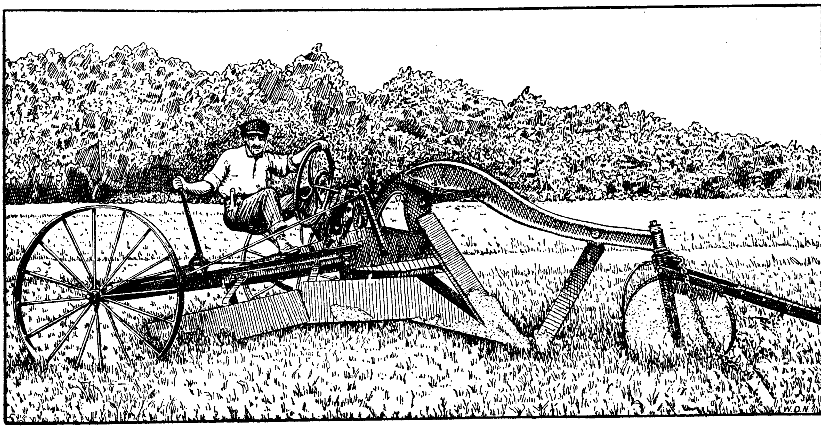

FIG. 4.—Ditching plow D.

WHEEL EXCAVATORS.

COMMON FEATURES.

The wheel excavators generally have steel bed frames rigidly braced, upon which the power equipment is mounted. Internal-combustion engines burning gasoline, kerosene, naphtha, or alcohol are perhaps most generally used, though steam engines and boilers are often preferred. The internal-combustion engines are preferable where it is important to avoid unnecessary weight.

The machine is usually supported upon two pairs of wheels, the front pair with flanges to prevent slipping sidewise from the line of the trench. The rear wheels carry most of the weight and therefore are large and broad. Many manufacturers now fit their machines, especially the heavier ones, with what are known as apron or cater-

pillar tractors (see figs. 7 and 11) instead of rear wheels. Each of these tractors consists of a series of wooden or iron crosspieces carried by parallel endless chains about a steel frame in such manner that the weight of the machine rests upon several crosspieces, and the large bearing surface thus obtained will support the machine upon very soft ground. As the excavator moves forward the chains lift the crosspieces at the rear and carry them to the front of the tractor.

Some machines move by applying power directly to turn the wheels or tractors, some by pulling on a cable anchored to a "dead man" buried in the ground ahead. The former method is preferable for firm soils, as no time is needed to place the "dead men." In soft soils, when power is applied to the wheels or tractors, these often slip, and the consequent "churning" causes the trench banks to cave and the machines to settle deep into the ground. When a tile-laying shield must be used, the amount of power necessary to

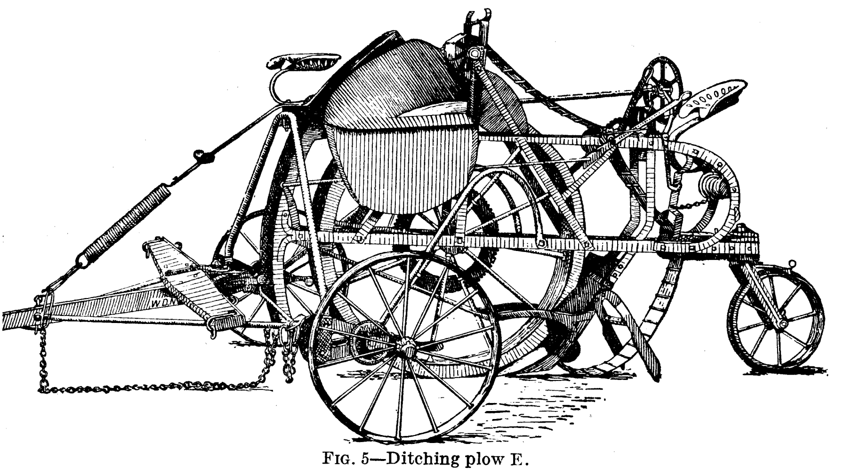

FIG. 5—Ditching plow E.

move the machine makes it impracticable to apply power directly to the tractors.

As already stated, the digging is done by buckets upon the rim of a wheel that is revolved in the trench (fig. 6), and as each bucket reaches the top of the circle the dirt falls upon a conveyor belt that can be shifted to deposit the spoil upon either side of the trench.

Levers are so arranged that the depth of excavation can be accurately controlled by the person operating the machine. An arm or gage is attached to the digging frame in such a way that the operator can sight across it to targets set along the line of the trench at a known height above the desired bottom and can thus cut true to grade.

For work in soils so soft that the sides of the trench will not stand unless supported, some machines may be fitted with shields following

close behind the digging apparatus, which keep the trench open until the tile can be placed in position. These shields are usually about 8 feet long, just sufficient to permit a man to work in them and lay the tile properly. The use of the shield of course increases the amount of power necessary to draw the machine ahead. The caving earth frequently causes the last-laid tile to "creep" forward with the machine, leaving an opening between tiles where much dirt might get into the drain and choke it. To prevent this, the man laying the tile must hold it back until it has left the shield.

MACHINE F.

The machine of this class in most common use (see fig. 7) has an

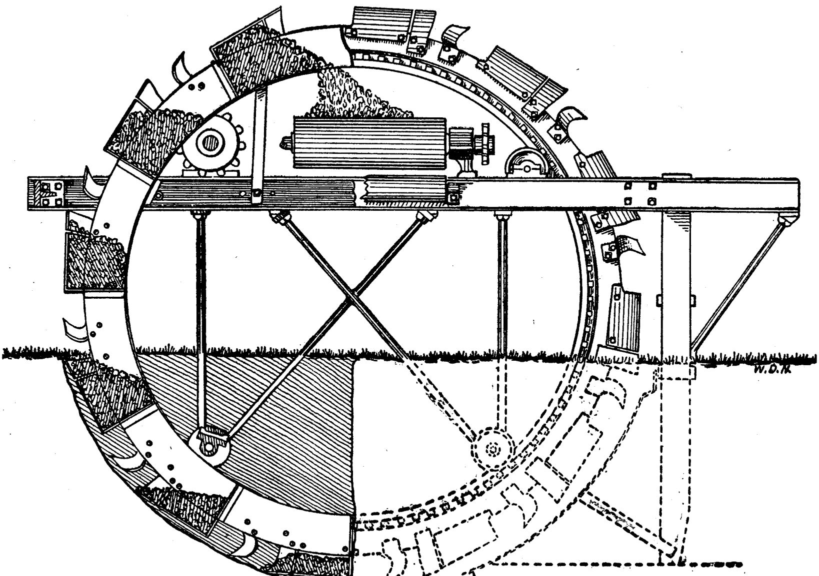

FIG. 6.—Digging mechanism of wheel excavators.

open excavating wheel; that is, a wheel with neither spokes nor hub. This wheel consists of two parallel iron rims held in their proper relative position by the buckets, which are fixed between the rims and firmly riveted to them. The rims are supported upon four pairs of small wheels (see fig. 6). One or both wheels of the pair just above the point where the digging is done are sprocket wheels, through which the power is applied. The buckets are open at the inner side, but close inside the rims is a metal plate extending nearly one-third the circumference of the excavating wheel that keeps the dirt in the buckets until it has been carried to the highest point; there it falls upon a belt conveyor, which deposits the spoil beside the trench. Between the buckets, which have semicircular cutting edges, side

cutters (see fig. 6) are bolted to the wheel for cutting the trench a little wider than the buckets and reducing the friction. The front end of the frame carrying the excavating wheel is hinged to the rear of the platform carrying the power equipment; the rear of the frame is supported on a shoe that slides on the bottom of the trench and makes a smooth, shallow groove for the tile. The maximum depth of digging is about two-thirds the diameter of the wheel. Either solid or skeleton buckets may be used. The former type is made of plates that fit the machine for digging loose, sandy soils; the latter type has bars instead of plates for the sides and bottom in order that

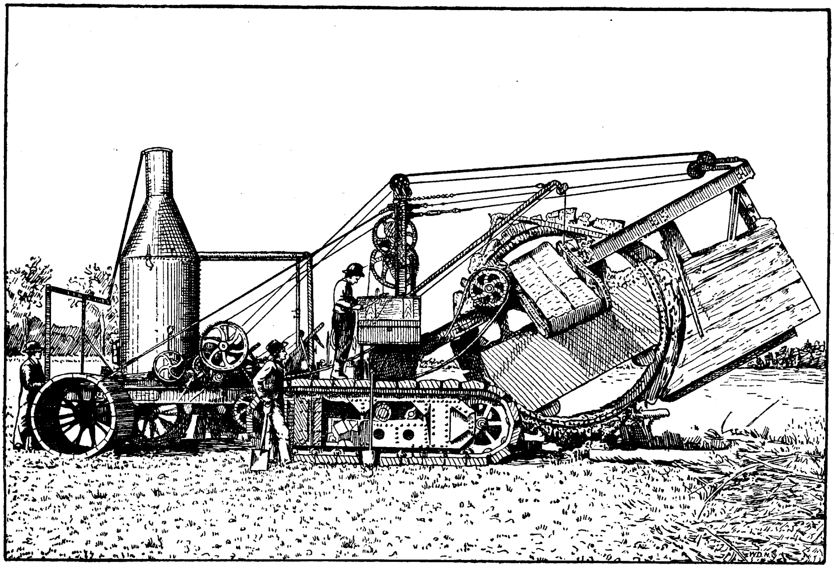

FIG. 7.—Wheel machine F, equipped with shield for use in caving soil.

wet and sticky soils will fall out more readily. Two cleaning devices are furnished to remove sticky earth from the buckets.

This machine is made in many sizes, digging trenches 11½ inches wide by 4½ feet deep to 54 inches wide by 12 feet deep. Its weight varies from 5½ to 51 tons. The weights and approximate selling prices for some of the smaller sizes, equipped with steam power and wheel traction, are as follows:

Sizes, weights, and costs of machine F.

Size of trench.	Weight.	Price.	Size of trench.	Weight.	Price.
	Tons.			*Tons.*	
11½ inches by 4½ feet	5½	$1,200	24 inches by 7½ feet	15	$4,800
14½ inches by 4½ feet	6½	1,[illegible]00	28 inches by 7½ feet	18	5,200
15 inches by 5½ feet	8½	1,750	32 inches by 7½ feet	20½	5,500
20 inches by 5½ feet	11	3,000	36 inches by 7½ feet	24	6,500
20 inches by 7½ feet	13½	3,800			

The three smallest sizes can be equipped with gasoline engines instead of steam engines and boilers for $200 to $250 additional, and on all but the last three mentioned apron tractors can be obtained instead of wheels at an increase of $200 to $400 in cost. Various gears are supplied for regulating the speed of the excavating wheel and the forward movement of the machine. The latter is accomplished by power applied to the rear wheels or tractors. The road speed of this machine is about 2 miles per hour. For railroad transportation the wheels or tractors must be removed from the larger sizes.

A large number of machines of this style have been manufactured and have given general satisfaction in ordinary soil conditions, although they have not worked with complete success in some tenacious gumbo soils. They have cut tree roots as large as a man's arm. Stones larger than the buckets will be rolled out if found near the surface of the ground, but when bedded deeply they must be removed by hand.

Machine G.

This is a comparatively new excavator very similar to machine F, the principal difference being in the buckets (see fig. 8). Each of these is like a broad, low T with arched top, attached by the vertical stem to a rib on the wide rim of the excavating wheel. The buckets are open at the sides. Two stationary cleaners, one on each side at the top of the wheel, scrape the dirt from the buckets into short chutes that drop it at the sides of the trench. These buckets were designed for very sticky soils, and for work in loose material are fitted with spring backs. Either steam or internal-combustion engines are used, the latter to burn kerosene, distillate, motor spirits, or gasoline. Either wheels or apron tractors can be obtained. The limits of digging of the various sizes are the same as for machine F, though the advertised weights of a few of the smaller sizes are a little greater.

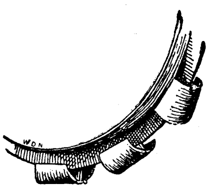

FIG. 8.—Buckets of wheel machine G.

Machine H.

Extreme lightness and low purchase cost are the most notable features of machine H (fig. 9). It is made in only one size, digging $4\frac{1}{2}$ feet deep, but will dig three widths. The greatest width, which is 16 inches, will accommodate 14-inch tile. The total weight, ready for work, is 3,600 pounds; the price is $1,800.

The machine is mounted upon four wheels having 8-inch tires, and the excavating wheel is placed between the front and rear axles. This wheel is raised or lowered as desired by cables passing over the top of the frame. Power is furnished by a 40-horsepower, 4-cyl-

inder gasoline motor weighing only 500 pounds, which is mounted over the rear axle. The machine is moved forward by pulling on a cable fastened to the front of the machine and looped over a pulley attached to a "dead man" ahead. It is easily drawn by team from one job to another.

The eight excavating buckets are of the open or skeleton type, and there is a spring cleaning bar for use in very sticky soil. For work in sandy material special frames or fillers are attached to the bars of the buckets. A unique feature of the buckets on this machine is that one side of each bucket is longer than the opposite side, so that one end of the cutting edge is in advance of the other and the result is a "diagonal draw" cut. Another special feature of this machine is that all the excavated material is not carried to the top

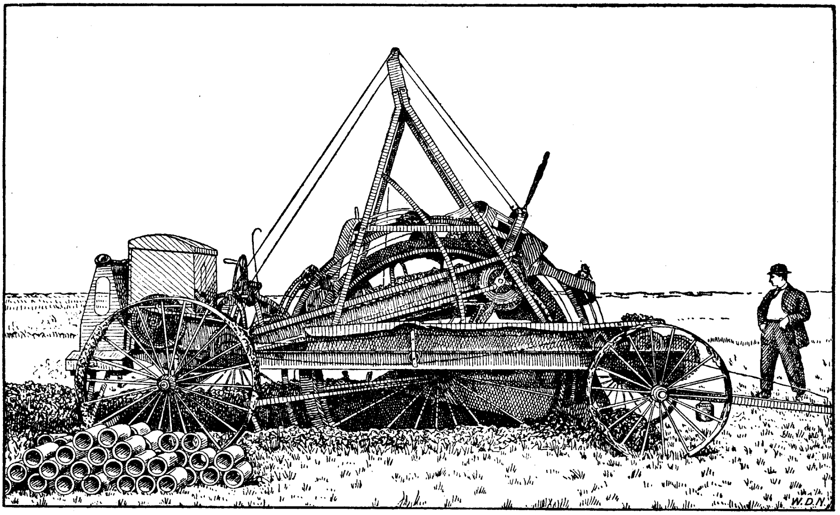

FIG. 9.—Wheel machine H.

of the wheel, but any loose earth falls out of the buckets soon after they get above the ground surface, upon a revolving cylinder that throws the dirt to the side of the trench. It is claimed that considerably less power is required to operate this machine, because the whole amount of excavated material is not lifted to the top of the wheel.

Excavator H is of rather recent manufacture, but all of this make so far tried seem to have been satisfactory. Sticky gumbo has given comparatively little trouble, and a machine has been operated in ground so soft that the wheels sank to the hubs in the mud. A crew of two men is desirable for trenching—one to operate the machine and one to clean the crumbs from the ditch and lay the tile. About 10 gallons of gasoline are used per day.

ENDLESS-CHAIN EXCAVATORS.

This class of excavator, like the wheel machines, has steel bed frames mounted upon two pairs of wheels and carrying steam engines and boilers or internal-combustion engines. Apron tractors are often used instead of the rear wheels. The digging apparatus is operated by a sprocket wheel at the upper end of the frame, receiving power through a chain drive from the engine (see fig. 10.) At the

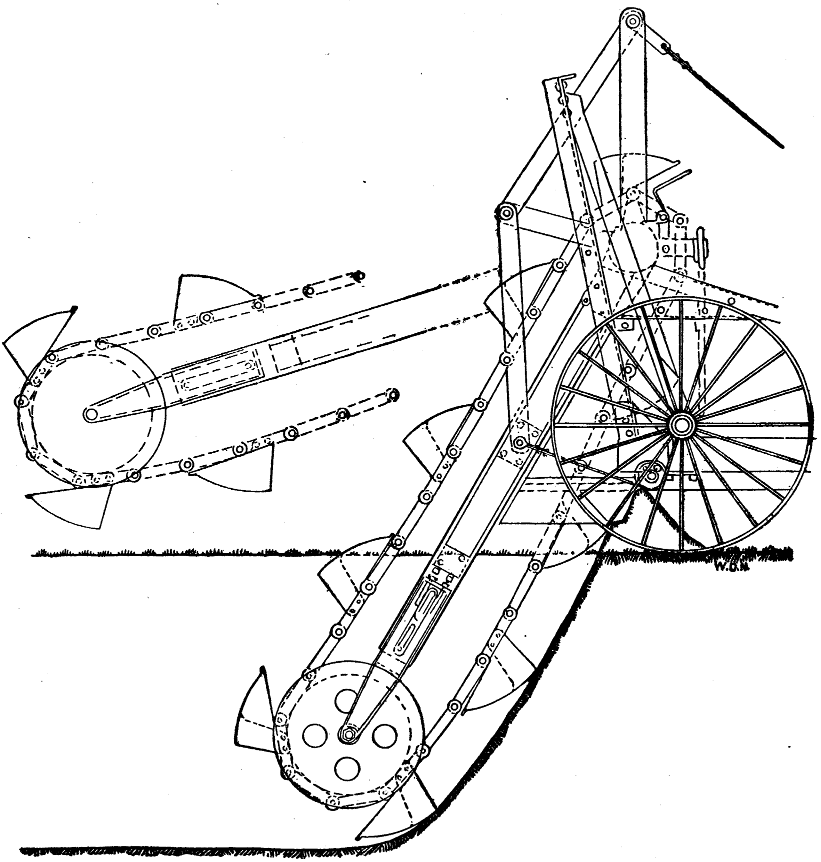

FIG. 10.—Digging mechanism of endless-chain excavators.

end of their upward movement the buckets empty their loads upon an endless belt which conveys the dirt far enough to the side that it will not fall back into the trench. Cutting knives or teeth on the lip of the bucket are often used in hard ground.

Devices for cleaning the buckets are provided. The depth of excavation is regulated by levers, gage, and targets in the same way as for the wheel excavators. Shields can be used to keep the trench from caving until the tile have been laid.

MACHINE I.

This excavator (see fig. 11) carries most of the weight on two tractors, each of 10 to 50 square feet bearing surface, depending upon the size of the machine and the character of the soil. The front wheels guide the machine and carry a little weight. The usual power equipment is a gasoline engine of the vertical water-cooled type with two to four cylinders. This is belt-connected to a friction drum, which transmits the power through a heavy sprocket chain to the excavating chain and the belt conveyer. The gaso-

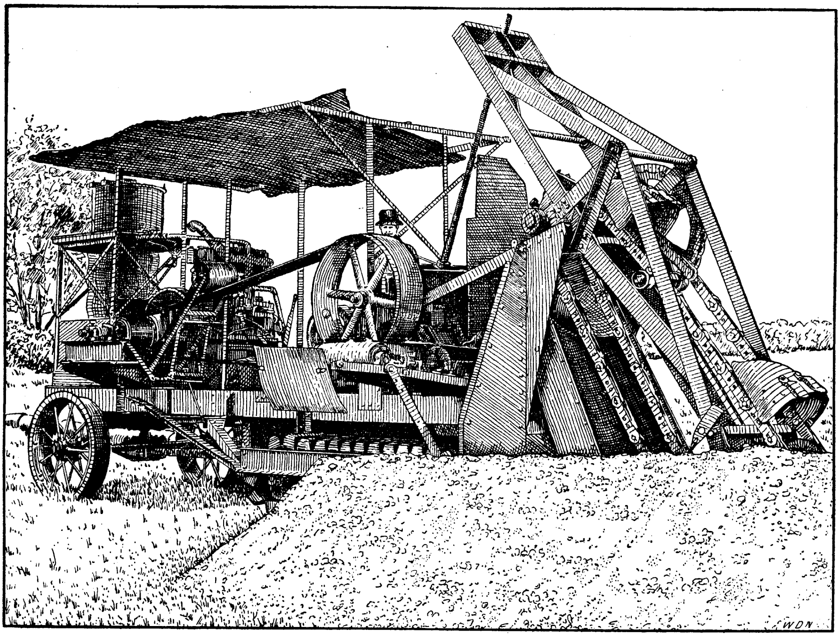

FIG. 11.—Endless-chain machine I.

line and water tanks are located ahead of the engine on the front of the bed frame. The machine moves forward by power applied directly to the tractors. Its average speed on the road, when not digging, is about $1\frac{1}{2}$ miles per hour. The manufacturers of this machine provide a device that prevents soft earth from working up between the boards forming the bearing surface of the tractor, eliminating a source of annoyance not uncommon to apron tractors generally. The excavating buckets are of the open conical scoop shape, and as each revolves about the driving wheel it is scraped by a cleaning device that causes the dirt to fall upon the belt conveyer. This conveyer can be shifted from one side to the other with little trouble, permitting the dirt to be piled on the side preferred.

The machine is made in two sizes, the smaller digging 12 to 22 inches wide and any depth not exceeding 6 feet, the larger digging 15 to 28 inches wide and any depth to 10 feet. The operator can adjust the width of the trench merely by changing the knives or reamers used with the buckets. The smaller machine weighs about 9 tons, is fitted with an 18-horsepower gasoline engine, and costs about $3,000. The larger machine weighs about 11½ tons and costs about $4,000. It may be fitted with a 25-horsepower gasoline engine, or with an 18-horsepower 8½ by 8½ inch steam engine and 25-horsepower vertical boiler. An attachment is manufactured which will cut ditches with sloping banks, having a maximum depth of 5 feet and a maximum top width of 7½ feet. Only one man is needed to operate this machine. The average fuel consumption is about 15 gallons of gasoline per day. For shipping from one railroad point to another, these machines can be loaded upon a flat car without dismantling.

Machine J.

A noticeable feature of this machine is that a third pair of wheels is used to support the rear end of the digging apparatus (see fig. 12). When working, the rear wheels are spread wide apart, so that the truck straddles the trench and the waste banks. For road travel and for railroad transportation the rear truck is narrowed to the width of the others. The front end of the frame supporting the buckets, and the greater part of the weight of the power machinery, is carried on the two large wheels of the middle truck. Spreaders can be used to widen the rims of these wheels, permitting the machine to travel over very soft ground. Both the front and the rear wheels can be steered so that turns of short radius can be made both on the road and when digging. Power is furnished by a gasoline engine. A friction clutch is used to prevent large rocks or other obstructions from breaking the machinery. This excavator ordinarily moves under power applied from the engine to the large middle wheels, but when a shield is used in the trench to prevent caving of the sides the machine is moved by pulling on a cable anchored ahead. The road speed is about 1½ miles per hour. The digging equipment is similar in general to that of excavator I already described. The buckets are of a special conical shape. The cleaning device is stationary, with a spring that makes the cleaner fit each bucket exactly, and has worked exceptionally well in sticky gumbo soil. There are two conveyor belts, one on each side, which meet under the middle of the bucket being dumped. When both conveyors are in a horizontal position the dirt is deposited on both sides of the trench; all may be placed on one side by merely raising the conveyor on the opposite side to a vertical position. The mechanism regulating the depth of cut is mounted upon the trailer frame that connects the

rear wheels and the forward part of the machine, and can be operated either by hand or by power from the engine.

Excavator J is made in three sizes. The smallest machine cuts 16 to 26 inches wide and 9 feet deep, weighs about 8 tons, is equipped with a 25-horsepower, 2-cylinder, opposed type, internal-combustion engine, and costs about $4,000. The middle size cuts 28 to 47 inches wide and 12 feet deep, weighs about 15 tons, has a 40-horsepower engine, and costs about $6,000. The largest machine cuts 28 to 58 inches wide and 20 feet deep, weighs about 18 tons, has a 40-horse-power engine, and costs about $6,500. An extension for digging deeper than the stated limits can be furnished for the two larger machines. Motor spirits, gasoline, or kerosene can be used for fuel. This machine weighs less than any other practical design, capable of digging to the same limits, that has yet been placed on the market. In the two larger sizes this excavator has a crane mounted on the

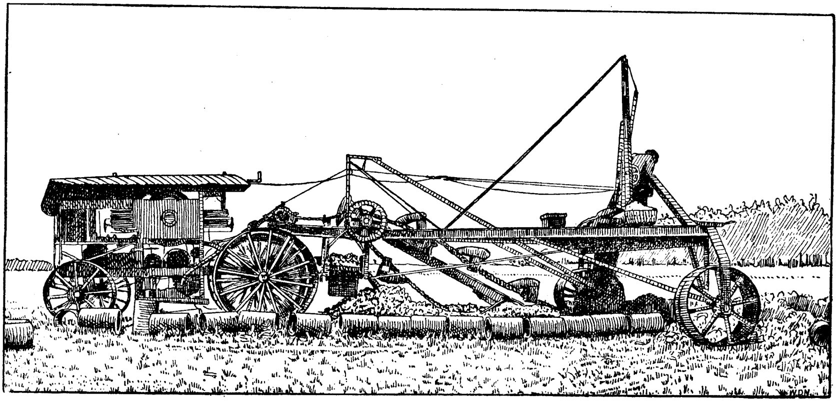

FIG. 12.—Endless-chain machine J.

trailer frame for lifting the tile from the side into the bottom of the trench. The windlass for the crane is usually worked by hand, but it could be operated by power from the engine. The entire trailer with the digging mechanism can be detached by removing one bolt and disconnecting the hoisting cable and the chain driving the buckets; the forward part of the machine then can be used as an ordinary traction engine for hauling or other power purposes. To run either of the larger machines two men are necessary—one to operate the traction and one to regulate the depth of cutting and to operate the tile crane.

MACHINE K.

The unique feature of machine K (see fig. 13) is that the excavating buckets are drawn vertically up the end of the trench instead of at a considerable angle. The advantage of this feature is that the machine will cut curves of unusually short radius. The machine moves on four

wheels, the rear pair large and having 24-inch tires that can be increased by spreaders to 48-inch width. The machine travels on the road at about $2\frac{1}{2}$ miles per hour. There are 10 cylindrical buckets attached to a roller chain, which travels on a rigid frame shaped like an inverted L, with the vertical stem toward the front of the machine. The buckets are filled as they rise vertically from the trench, then pass back over the horizontal part of the digging frame, and drop their loads upon the belt conveyor as they turn about the end of the frame. Returning forward horizontally they pass over a cleaning

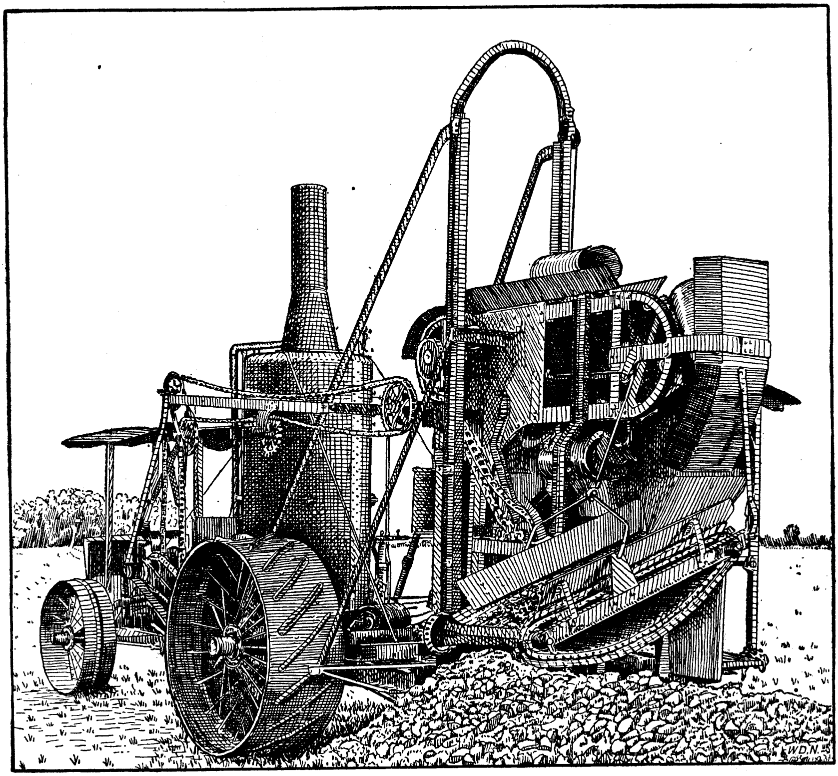

FIG. 13.—Endless-chain machine K.

plate before turning downward to the bottom of the trench. The cleaning plate just fits the buckets and is especially valuable in very sticky soils. It is in turn kept clean by a gear-driven scraper. The buckets are slotted on the outer side and the bottoms are hinged to permit passage over the cleaning device and its support. A "crumber" is dragged behind the excavating frame, to scrape up any loose earth and to make a groove in the bottom of the trench that will keep the tile in perfect alignment. The depth of cut is regulated accurately by raising or lowering vertically the whole digging frame and mechanism.

This vertical-cut excavator is made in two sizes. The smaller size cuts 13 to 17 inches wide and $6\frac{1}{2}$ feet deep, has a 25-horsepower, 2-cylinder, opposed type gasoline engine, weighs about $5\frac{1}{2}$ tons, and costs approximately $3,000. The larger size cuts 17 to 24 inches wide and 9 feet deep, is equipped with a 15-horsepower steam engine and 18 horsepower vertical boiler, weighs 10 tons, and costs about $4,000. The gasoline engine of the smaller machine is mounted over the forward truck' but the steam engine and boiler are mounted between the two trucks on a strong bed frame with the water tank in front. The digging apparatus on each size is placed just behind the rear truck.

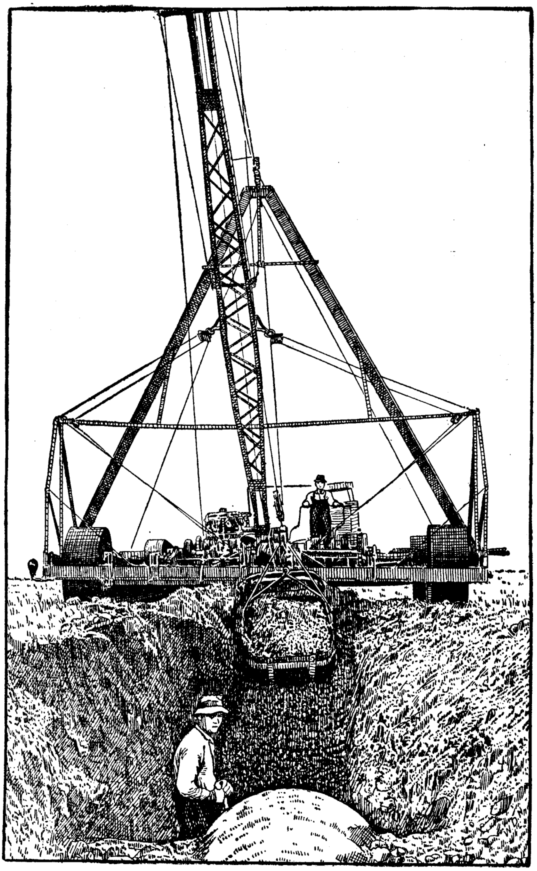

FIG. 14.—Scraper machine L.

In beginning a trench, a shallow hole must be excavated into which the digging frame is lowered before the buckets can be started. The smaller machine can be operated by one man. This size can cut on a curve of 50 feet radius. The larger size requires a crew of three men—one to operate the digging machinery, one to tend the engine and boiler, and one to haul water. About 30 barrels of water and a ton of coal are needed per day.

SCRAPER EXCAVATORS.

As previously stated, the machines in this class are merely adaptations of excavators originally designed for digging large ditches. They are not suited to trenching for small tile, and seem to be used entirely for large tile mains.

Machine L.

The illustration (fig. 14) shows a drag-line excavator of ordinary design being used for laying a main drain of very large tile. Upon the bed-frame is mounted a swinging boom, the upper end of which is supported by a cable from the top of the A-frame, also mounted upon the bed of the machine. The bucket or scoop hangs on a cable from the upper end of the boom. It is filled by being dragged lengthwise of the ditch by a cable pulling directly from the front of the machine. The loaded bucket is raised by the rope from the boom, which then swings it to the waste bank to be dumped. Another cable from the hoisting engine may be run over a sheave on the end of the boom to lift the tile into place from beside the trench. Either steam or gasoline power may be used to do all the work of digging, swinging, and dumping the dirt, and of lifting the tile into place. Only one man is required to operate the machine, but a second man is needed to attach the lifting cable to the tile beside the trench, and a third to fit the tile as they are placed in position.

Machines of this drag-line type are sometimes fitted with a guide rail for the bucket to give better control of the place and depth of cutting. Such guides may help in making a clean, smooth trench. This type can not dig to grade as accurately as the wheel and endless-chain types, and the bed for the tile must often be smoothed with shovels.

BACK-FILLING AND TILE-LAYING DEVICES.

Some operators of trenching machines have equipped the excavators with mechanical devices for filling the trenches after the tile have been laid. These may be used with either wheel or endless-chain machines, whenever sufficient power is available. One such arrangement, manufactured by the makers of excavator J, consists of a conveyor belt to carry the dirt from the excavator to a point behind the man laying the tile, and there to dump it into the trench (see fig. 15). The frame supporting the belt is mounted on a truck that straddles the trench. Considerable power is required to operate this conveyor.

Simple devices are V-shaped plows attached to the excavators by means of cables. They may be made of either metal or wood. As the excavator moves forward the back-filler is dragged along, wide end foremost and one arm on each side of the trench, scraping the waste banks into the ditch.

Steel chutes for laying tile up to 12 inches in diameter, without requiring a man in the trench, have been attached to trenching machines. These have not been wholly successful, at least partly because tile slightly irregular in form can not be fitted together as is done when they are laid by hand.

COST OF TRENCHING BY MACHINERY.

The cost of trenching by machinery depends upon a number of factors, some of which are often overlooked in considering the purchase of such a machine.

The cost of operation per day will depend upon the number of men and teams employed, the wages paid, and the amount and cost of fuel. In respect to labor, the internal-combustion engine has the advantage, for usually only one skilled operator is needed, while steam equipment requires also a fireman and a team with driver to haul fuel and water. Not all workmen are paid when work is delayed by unfavorable conditions or for repairs, but the operator and frequently his helper are employed in making the repairs, and it may

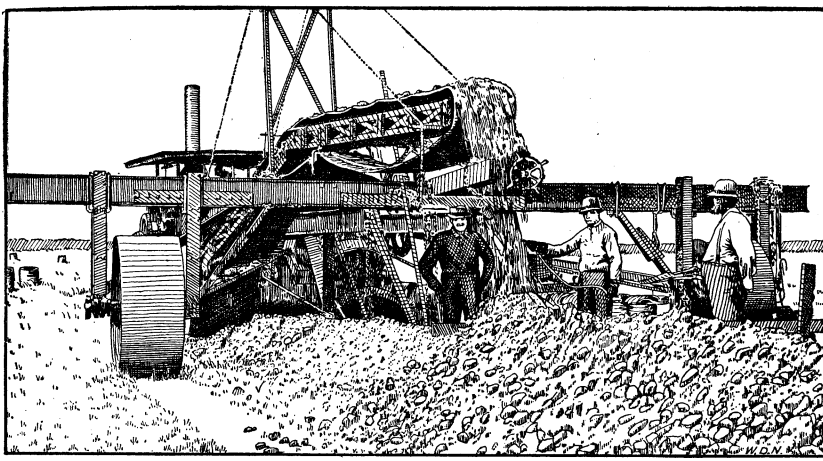

FIG. 15.—Back-filling belt conveyor, attached to machine J.

sometimes be necessary to pay the operator for time lost owing to such causes as rain. Laying tile, blinding,[1] and back-filling the trenches of course require further labor, which would be the same for any machine or for hand labor, unless a back-filling device is attached to the excavator. In tile-drain contracts only three items are usually covered: trenching, laying, and blinding.

The amount of work done per day will depend upon the soil conditions, the strength and efficiency of the machine, and the skill of the workmen. One of the most difficult soils to work is a wet, sticky clay; a sandy subsoil will often cause difficulty. The presence of large stones or tree roots will of course interfere greatly, more so than with hand ditching. Very hard subsoil may make progress slow. Some of the machines have worked through 15 inches of frost, but this is severe work for any excavator. Some clays become

[1] "Blinding" is carefully placing the first few inches of earth around and over the tile to hold it in position and protect it when the trench is being filled.

baked hard enough in dry periods to make trenching slow. These various conditions will show the weak points of a machine, and may cause considerable expense for repairs, due not only to cost of repair work, but also to time lost.

It is interesting to note a few instances of work by machines. In a saturated loam soil, a machine F dug 105 rods of trench 14½ inches wide and 40 inches deep in 9 hours (an unusually good day's run). In a heavy, sticky clay, another machine of the same type dug 280 rods of 12-inch trench 3½ to 5½ feet deep at the rate of 61 rods in 10 hours, the best day's work being 91 rods. On another job where the soil was saturated at depths of 3 to 5 feet, progress by a similar machine on a 12-inch trench was as follows:

Performance of a trenching machine of the wheel type (machine F).

Top soil.	Subsoil.	Average depth.	Length.	Time.	Average rate.
		Feet.	*Rods.*	*Days.*	*Rods per day.*
Clay loam	Silty clay	3.7	30.3	1	30.3
Silty clay loam	do	5 to 5.5	42.5	3	14.2
Silty clay loam	Silty sand	5 to 5.5	21.2	2	10.6
Sandy loam	do	5 to 5.5	212.0	23	9.2
Totals and means		5.1	306.0	29	10.55

In the sandy subsoil the sides of the trench caved badly. The rates on this work are much more nearly indicative of the average performance that may be expected for a job than the two selected examples given. In northern Illinois the owner of an excavator of type H has found that his machine will dig about 100 rods of trench 3 feet deep per 10 hours' actual digging.

The matter of lost time is of great importance, for the owner is usually losing money when his machine is not digging. The portion of a year during which a machine does not work is surprisingly great, even to many drainage contractors, and will explain why trenching with a machine costs so much more than one ordinarily will reckon even after watching the machine work for several days under adverse conditions. While a machine is on the work there is loss due to stormy weather, and sometimes due to flooding of lowlands; there are delays for repairs, including waits for new machine parts; and there is time spent in moving from one trench to another. Interest and depreciation charges accrue during all these delays, as well as on Sundays and while the machine is being transported between jobs or lies idle waiting for new work. In the northern States there are two to four months of the year when frozen ground and cold weather prevent work of this kind, except at rates too high for farm drainage. A contractor who has his machine actually digging 200 days in the year is fortunate.

It will be helpful to examine the record of one large contract on which the conditions were fairly good. The machine of type F arrived June 24 and began digging July 3; trenching was completed October 1. Of the 100 days the machine was on the job, there were 14 Sundays, 61 days of machine work, and 25 days lost on account of repairs, rain, and miscellaneous delays. The main drain, of 5-inch to 12-inch tile, was 358 rods long and of about 3.9 feet average depth. The lateral drains, of 4-inch and 5-inch tile, had a total length of 6,055 rods and an average depth of about 2½ feet. Of the 61 days of work, 12 were required for the main drain and 49 for the laterals. The average rates of progress, considering only the days of actual work, were 29.8 rods per day for the main drain, and 123.6 rods per day for the laterals. If the 25 lost days be included, the working days actually used were 15 and 71 for the main and the laterals, respectively, and the average rates of digging are then computed as 23.9 and 85.3 rods per day.

The cost of this contract may be estimated as follows, since rather accurate data are available:

Freight on machine, water wagon, etc.		$78.54
Repairs and renewals		109.92
Fuel, about 24 tons coal, delivered		94.90
Lubricating oil		13.95
Labor:		
Operator, at 22½ cents per hour	$123.58	
Fireman, at 20 cents per hour	109.80	
Team and driver, at $2 per day	122.00	
		355.38
Horse feed		60.12
Incidentals		28.85
Camp equipment for laborers		29.55
Total cost of operation		771.21

To the foregoing cost of operation must be added the cost of superintendence and of "overhead" charges paid by the contractor, such as office rent, clerical hire, and travel in securing the contract; these might be assumed very roughly as $150. While the machine was on the job only 100 days, there should be added the time that the machine was in transit to the job, the time used for repairs before shipment to the work (in this case new boiler flues were placed and some machining of parts was done), and a proportionate part of the time the machine is idle between contracts and on account of winter weather. It is reasonable to assume that interest and depreciation should be charged for about five months. The machine probably cost, new, about $1,750. Depreciation on machinery of this kind is especially difficult to determine accurately, but it may be assumed that by the end of four years the excavator will have been practically rebuilt; the bed and perhaps the engine will be in fair condition, but

renewals of other parts will have been made many times. On this basis the cost of that part of the contract covering the trenching machine's work is computed.

Cost of operation	$770
Superintendence and overhead charges	150
Interest	50
Depreciation	200
Total	1,170

Dividing this cost in the ratio of 15 to 71, the days required for the main and the laterals, the cost of trenching only is computed as 57 cents per rod for the main and 16 cents per rod for the laterals. If the labor for laying and blinding the tile cost $3.82 per day for the 61 days the machine was digging, the total cost of trenching, laying, and blinding was 70 cents per rod for the main, and 19 cents per rod for the laterals. The main averaged 3.9 feet deep, and one-third was wide enough for 10-inch and 12-inch tile; the laterals averaged 2½ feet deep, all of minimum width. The cost for the main is unusually high, while that for the laterals is unusually low. In the early part of the work, including the work on the main, digging was slow because the ground was very dry and hard. Several buried stumps caused minor breaks and some delay. Because one lateral was dug and the tile laid, and rain came before connection was made to the main, about 500 feet of 5-inch tile had to be removed, cleaned, and relaid.

It is interesting to compare the foregoing contract job with the following work done by a landowner. A second-hand steam trencher of type F was bought for $500 on January 8, and not long after the completion of the work on November 5 it was sold for $400. The work on this farm was the total done by the machine in the year. The total length of trenching was 3,830 rods, the average depth about 32 inches; 5-inch tile was the largest laid. The cost items were:

Freight on machine		$20.00
Travel to purchase machine		17.95
Repairs and renewals		203.09
Fuel:		
4 tons coal	$20.00	
50 cords wood (cut on farm)	100.00	
		120.00
Oil and grease		7.10
Labor:		
Operator, at 20 cents per hour	$276.80	
Helper, at 15 cents per hour	207.60	
Team and driver, 17½ cents per hour	121.10	
		605.50
Interest on cost of machine		30.00
Depreciation		100.00
Total cost of trenching		1,103.64

The cost per rod was thus 28¾ cents. The cost of laying and blinding the tile was $331.70 for 3,830 rods, or 8½ cents, making the total cost 37¼ cents per rod for trenching, laying, and blinding. The top soil was loam, overlying a compact silty clay subsoil. A good many small bowlders were encountered, and hardpan was sometimes found where the cutting was as deep as 3½ feet.

A machine of type H worked from January 1 to April 18 in stiff, heavy clay. The total length of drain was 3,075 rods, including about 1,200 feet of 10-inch and 12-inch tile; the average depth 3¼ feet. For about 600 feet, 6 inches of lime rock was encountered that required blasting. About one-third of the length was through a hardpan subsoil that could not be shoveled by hand until it had been loosened with picks. Frequent rains kept the ground saturated most of the time. Of the 92 working days, 32 were lost on account of rain and repairs. The cost of trenching, laying, and blinding, including setting grade stakes and leveling, but not back-filling, was as follows:

Labor	$606.64
Repairs	46.65
Gasoline, oil, etc	58.27
Board for part of crew	51.00
Interest and depreciation	240.00
Total	1,002.56

This is equivalent to 32.6 cents per rod. There was no freight to be paid, and the farmer moved the machine from one drain line to the next. Interest and depreciation are computed at $4 per day of actual digging, which seems reasonable for this machine, if kept fairly busy.

The same machine worked from April 20 to June 6 in a sandy loam with weather and soil conditions favorable, although one rain caused some little caving of trenches. The length of drain was 1,450 rods, including 600 feet of 10-inch and 12-inch tile; the average depth was 3 feet. Of the 42 working days, 3 were lost on account of rain, 3 for repairs, and 8 waiting for necessary work by another contractor, all of which are charged in the following cost:

Labor	$259.90
Gasoline, oil, etc	31.50
Repairs	16.40
Board for men	30.00
Interest and depreciation	112.00
Total	449.80

This is equivalent to 31 cents per rod for setting grade stakes, leveling, trenching, laying, and back-filling. The cost of the delay for another contractor amounted to $38.80, or 2.7 cents per rod. There were no freight or hauling expenses on this contract.

The foregoing figures show a considerably greater cost than such work is generally supposed to involve; however, the writer believes that when the total expense and the amount of work done in the whole year are counted up the costs given will be found not far from the average.

For tile trenching and laying by hand, where experienced men are employed, the rate of progress for one bottom man and one top man for the smaller size of tile laid not more than 3 feet deep, is ordinarily 15 to 30 rods per day, depending largely upon soil conditions. In some sections of the country, where the use of unskilled colored labor is necessary, the same number of men will put in, even with good supervision, only 5 to 8 rods per day per man; the cost for this labor per man is, of course, considerably less than for the other. Hand trenching, laying, and blinding by experienced men in good loamy soils costs from 25 to 40 cents per rod for depths not exceeding 36 inches, and in sticky soils from 40 to 50 cents per rod.

It will be noted that there is not a great difference in the cost of trenching by hand and by machine. The advantage of the latter method is in the shorter time required tc install drains and the less trouble in securing the few workmen wanted. Men capable of satisfactorily operating a trenching machine can usually be found, even where it is impossible to secure workmen to do acceptable hand trenching without close and constant supervision. On the other hand, a farmer buying an expensive machine to do a small amount of work might experience some difficulty in keeping it busy with profit until it can be sold.

SELECTING A TRENCHING MACHINE.

In selecting a trenching machine, the prospective purchaser should consider carefully the amount of work to be done by it, the dimensions of the trenches to be dug, the nature of the soil to be excavated, and other conditions of work.

The wheel type of excavator is most generally used for installing farm drains, probably owing to a lower cost for the smaller sizes than the cost of the chain type. Machines of the latter kind have greater range in size of trench than wheel excavators of the same weight, and seem to be better adapted for work when there is a great deal of 8-inch tile and larger. When the greater portion of a job is small tile at ordinary depths, of course the excavator should be suited to the major part. Some of the machines are so constructed that the excavating mechanism can be easily detached, leaving the other part available as a traction engine or to furnish power for running miscellaneous farm machinery.

The weight of the excavator is important in digging soft earth, and may require the use of apron tractors instead of the less expensive wheels. Sometimes internal-combustion engines are preferred to

steam equipment because they weigh less. Internal-combustion engines are also quite popular for the smaller machines because the number of men required for operation is less, but they are not so dependable for continuous operation as steam engines, and the latter equipment is therefore generally preferred for large machines. In some localities gasoline and similar fuels are not easily obtainable, and if wood is plenty and cheap this may make steam machinery more desirable. When the same engine is to be used for grinding feed and for similar work, the readiness with which internal-combustion engines can be started makes them desirable.

A trenching machine should be constructed of good materials and be well proportioned for strength. Simplicity of construction is desirable. The great loss of time on a job due to faulty operation of internal-combustion engines and to delays for repairing broken chains, bolts, gears, and other pieces, requires the elimination of as many parts as practicable. The cost of repairs depends a great deal upon the skill and care of the operator. Comparatively little time is consumed in moving from one drain to another.

While it is manifestly impracticable to make a hard and fast rule which the landowner may apply in selecting a trenching machine for his particular needs, the following general statements may be of assistance.

If a landowner expects to install 100 rods of tile drain in soil which would require picking, but which contains no rock, he would be justified in buying a ditching plow costing as much as $20. If he proposes to construct 1,500 rods of tile drain in soil free from rock and large roots, the landowner can well afford to purchase a horse-drawn ditching plow costing from $250 to $300; and if it be assumed that the owner can sell his machine, when his ditching is completed, for $100, he would be justified in purchasing such a machine for the construction of 1,000 rods of drain. For the installation of as much as 5,000 rods of drain in a soil free from rock and large roots, the purchase of a power-driven trenching machine costing as much as $1,500 probably would be justified, on the assumption that the machine could subsequently be sold for one-half its original cost. Very economical results are often to be obtained where several landowners unite in the purchase of such a trenching machine as is most suitable for their combined work.

Machines costing over $1,800 are suitable for contractors, owners of large plantations, and others having an unusual amount of trenching to do. However, landowners who have at least 5,000 rods of drain to construct and who intend to buy a power tractor, should investigate the suitability of some trencher having a detachable tractor that, when separated from the digging apparatus, would fulfill the purposes of any other tractor.

CONCLUSIONS.

In comparing the real costs of different machines and implements one must consider not only the purchase price and the operating cost for fuel, oil, and labor, but also repairs, interest on the investment, and depreciation. The interest on $20 invested in a plow is not large, repairs will cost little, and the implement will last many years. For a $3,000 excavator the interest charge would be $180 per year at 6 per cent, depreciation might be $450 or more per year, and repairs would be considerable. Operating expenses and repair costs depend largely upon the amount of work done, but interest and depreciation continue whether the machine is in operation or stands idle. Therefore the owner of an expensive machine must keep it busy a large part of the time if his investment is to be profitable.

On large jobs costly excavators may profitably be employed, but an inexpensive tool may be most economical for work that can well be done a little at a time when men and teams regularly employed on the farm might otherwise be idle. One of the greatest advantages of the large machines, from the farmer's viewpoint, is that the work is done rapidly; from a contractor's viewpoint there is often great advantage in using only a few men, as the employment of large numbers often involves labor difficulties. The larger machines can be used most advantageously where the drains are long and parallel.

Work is slow and costly in caving soil, in boiling quicksand, and in sticky gumbo. Large stones and roots cause annoyance and delay, and if in large quantity may make hand spading the cheapest method of excavation.

The cost data given on the preceding pages must be used with extreme caution, principally because the kind and condition of the soil and the skill of the operator affect the cost so greatly. The quality of the work also depends upon the carefulness and experience of the operator. Each purchaser must consider the limits of the work he will have to do and the conditions to be encountered, then determine what machine will best meet the requirements as a whole.

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